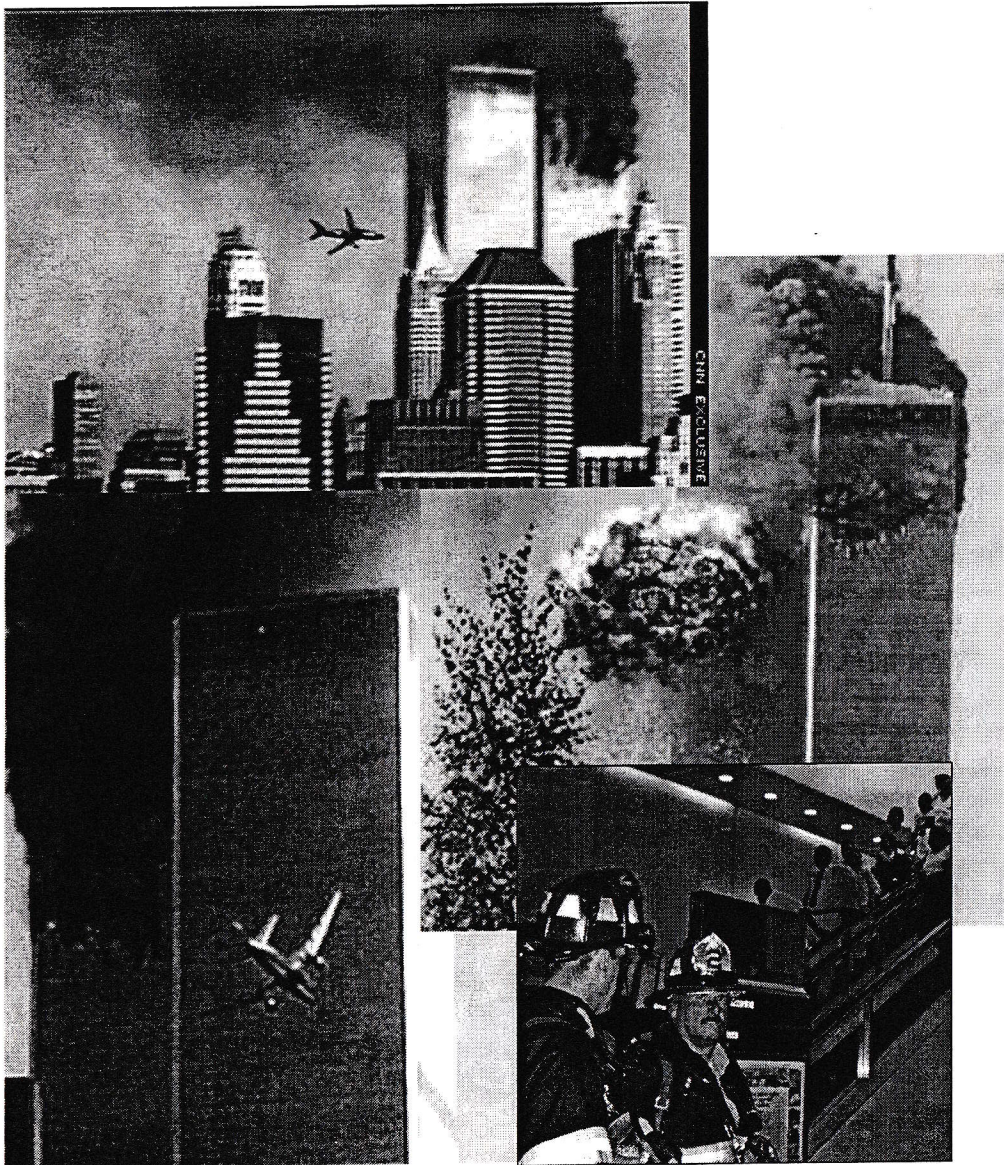


# I. National Building and Fire Safety Investigation of the World Trade Center Disaster (\$16.0 M)



## Goal:

- To investigate the building construction, the materials used, and the technical conditions that combined to cause the disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, and used; and
  - Improved tools, guidance for industry and safety officials, revisions to codes and standards, and improved public safety.

## Objectives:

- Determine technically, why/how the buildings, WTC 1 and 2, and WTC 7, collapsed following the plane impacts.
- Determine why the injuries and fatalities were so low/high, including all technical aspects of fire protection, response, evacuation, and occupant behavior and emergency response.
- Determine whether then-current procedures and practices were used in the design, construction, operation, and maintenance of the WTC buildings as these factors related to the collapse of the buildings and associated injuries and fatalities.
- Identify building and fire codes, standards, and practices that warrant revision.

## What/When:

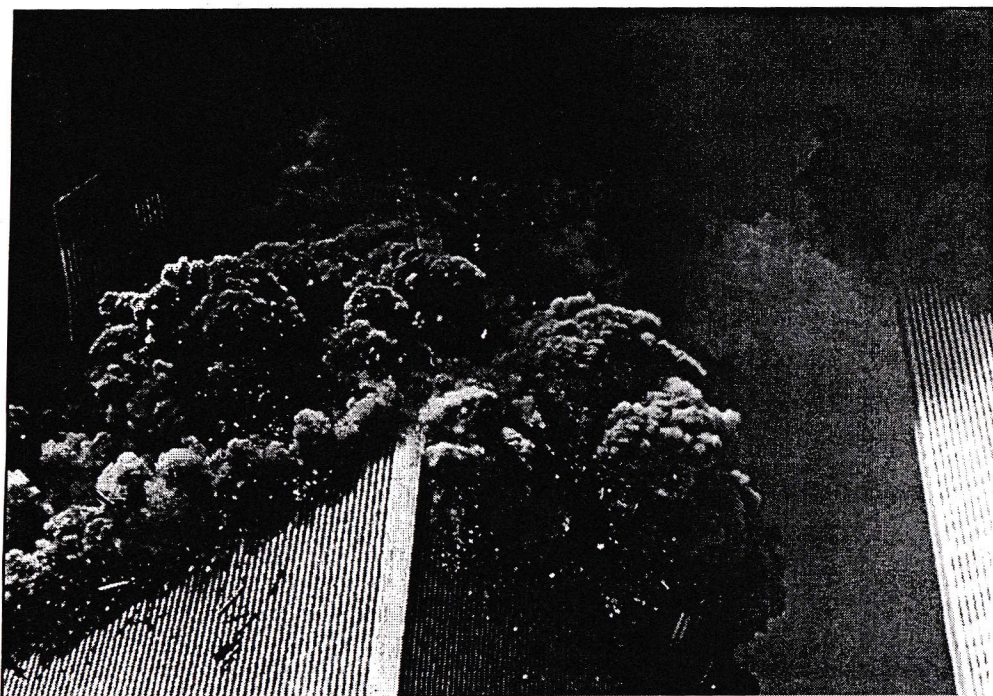
- Final Technical Report. Estimated 24 months.



# Legislative Authorities

## **Structural Failures [P.L. 99-73, Sec. 7; 15 U.S.C. 281a]**

The National Institute of Standards and Technology, on its own initiative but only after consultation with local authorities, may initiate and conduct investigations to determine the causes of structural failures in structures which are used or occupied by the general public. No part of any report resulting from such investigation shall be submitted as evidence or used in any suit or action for damages arising out of any matter mentioned in the report.



## **Fire Prevention and Control Act [P.L. 93-498, Sec.16, (a), (3)]**

NIST conducts and supports research on all aspects of fire with the aim of providing scientific and technical knowledge applicable to the prevention and control of fires. The Act authorizes NIST to conduct "...operation tests, demonstration projects and fire investigations in support of the activities set forth in this section."

# Prior NIST Investigations...

- **Earthquakes**
  - San Fernando, CA (1971)
  - Mexico City, Mexico (1985)
  - Loma Prieta, CA (1989)
  - Northridge, CA (1994)
  - Kobe, Japan (1995)
  - Kocaeli, Turkey (1999)
- **Hurricanes**
  - Camille, MS/LA (1969)
  - Alicia, Galveston, TX (1983)
  - Hugo, SC (1989)
  - Andrew, FL (1992)
  - Hurricane Mitch and Georges, LAC (1998)
- **Construction/Building**
  - Skyline Plaza Apartments, Bailey's Crossroads, VA (1973)
  - Willow Island Cooling Tower, WV (1978)
  - Kansas City Hyatt Regency, Kansas City, MO (1981)
  - Riley Road Interchange, East Chicago, IN (1982)
  - Harbor Cay Condominium, Cocoa Beach, FL (1981)
  - L'Ambiance Plaza, Hartford, CT (1987)
  - Ashland Oil Tank Collapse, Floreffe, PA (1988)
  - U.S. Embassy, Moscow, USSR (1987)
  - Murrah Federal Building, Oklahoma City, OK (1995)
- **Tornadoes**
  - Jarrell, TX (1997)
  - Spencer, SD (1998)
  - Oklahoma City, OK (1999)
- **Fires**
  - DuPont Plaza Hotel, San Juan, PR (1986)
  - First Interstate Bank Building, Los Angeles, CA (1988)
  - Loma Prieta Earthquake, CA (1989)
  - Hillhaven Nursing Home (1989)
  - Pulaski Building, Washington, D.C. (1990)
  - Happyland Social Club, Bronx, NY (1990)
  - Oakland Hills, CA (1991)
  - Hokkaido, Japan (1993)
  - Watts St, New York City (1994)
  - Northridge Earthquake, CA (1994)
  - Kobe, Japan (1995)
  - Vandaila St, New York City (1998)
  - Cherry Road, Washington, DC (1999)
  - Keokuk, IA (1999)
  - Houston, TX (2000)
  - Phoenix, AZ (2001)

## Results:

- Probable technical cause
- Lessons learned: successes and failures
- Improvements to standards, codes, and practices
- Establish future research priorities

## Authorities:

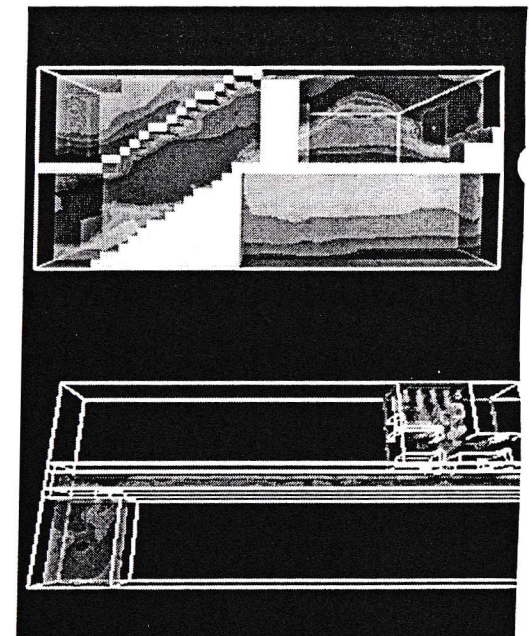
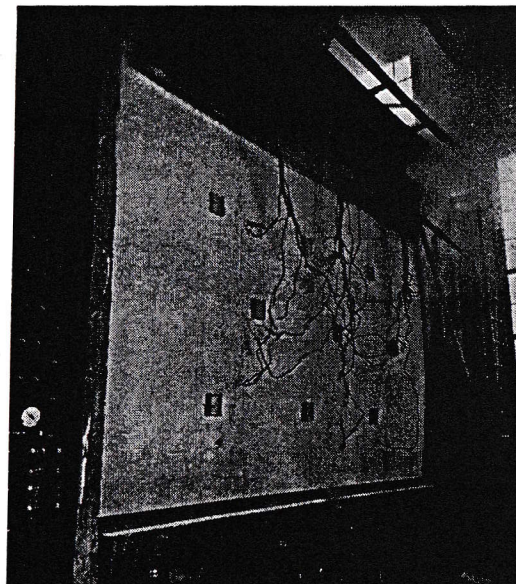
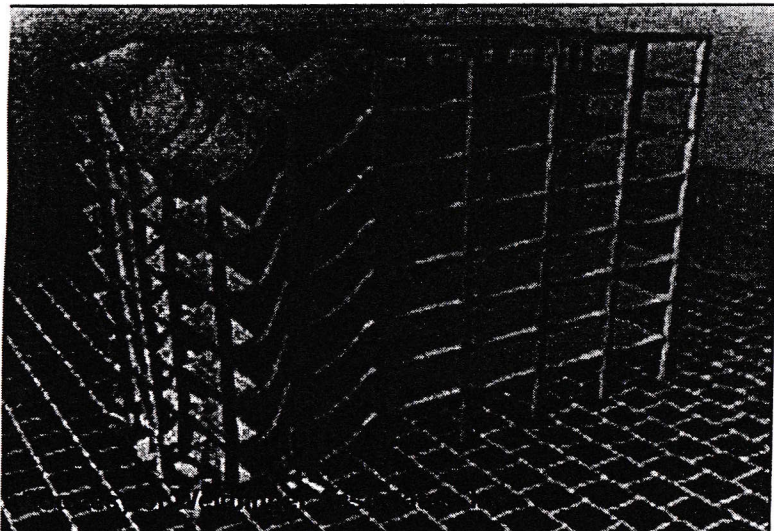
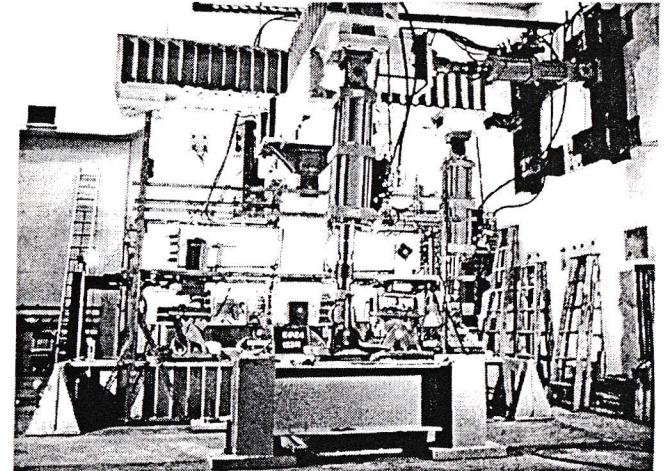
- ***NIST Act (1986)***: structural investigations
- ***NEHRP Reauthorization Act (1990)***: earthquakes
- ***National Post-Storm Data Acquisition Plan***: wind storms and floods
- ***Federal Response Plan***: structural and fire safety; disaster operations and situation assessment; urban and industrial hazard analysis
- ***Fire Prevention and Control Act (1974)***: fire investigations



## II. Structural Fire Protection \$20.3 M

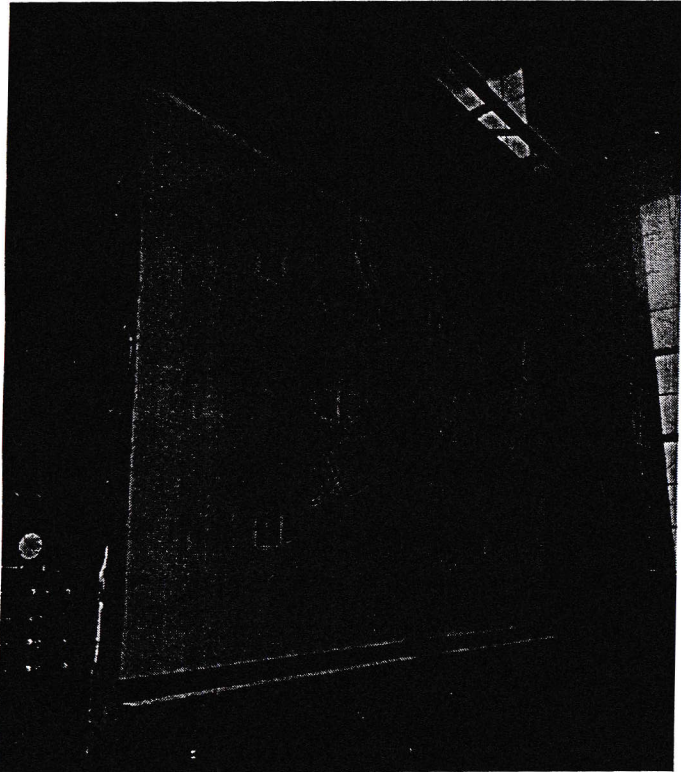
- Fire safety design & retrofit of structures
- Method of fire resistance determination
- Mitigation of progressive collapse
- Improved fire resistance coatings

**Partners:** ASCEC (AISC, ACI, SFPE, NFPA, CASE, Council on Tall Buildings, ICC, SEAoNY, TMS, NCSEA), FEMA, USACE, DTRA, NRC, NRCC, mat'l ind., NSF, FM Global, ASTM, ISO, CII, ACI, AIA, UL, universities,...





# METHOD OF FIRE RESISTANCE DETERMINATION



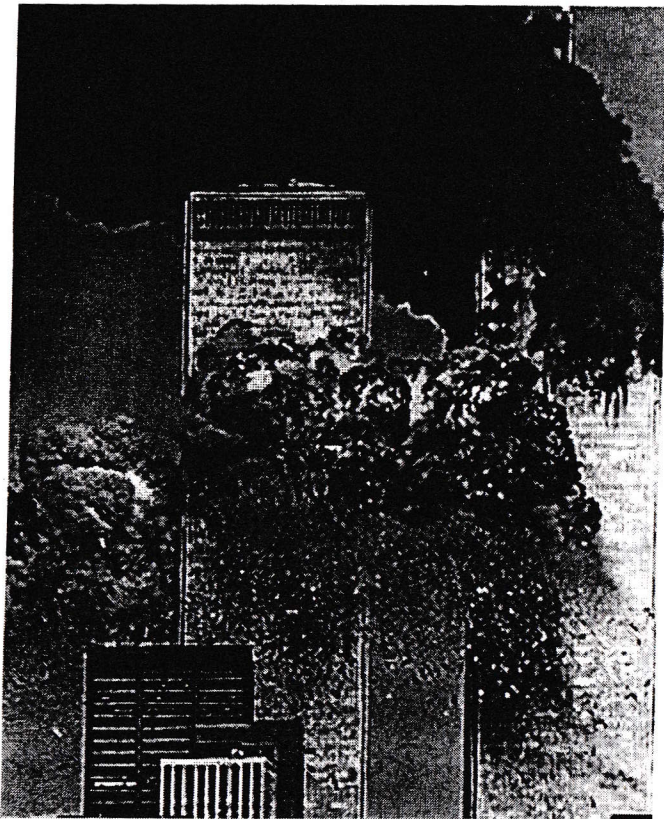
*Research is needed to revise the ASTM E119 test adopted in 1933.*

- **Cost:** \$3.7 M

- **Need:** New materials, measurement methods and analytical tools can provide more effective fire resistance for building materials. Standard tests (e.g., ASTM E119) are ill-suited to capture the value of these advances.
- **What:** A method will be developed for incorporating modern measurement and analytical methods into science-based fire resistant coating tests, and for modernizing related building codes and construction practice.
- **When:**
  - Workshop (12/01)
  - National strategy (9/02)
  - Guidance for improved methods (9/04)
- **Partners:** Building materials, construction, insurance industries; NFPA, FM Global, ICC, SFPE, ASTM, ANSI/ISO, ASCE, AIA, CII, ACI, AISC
- **Lead:** NIST (W. Grosshandler)



# Fire Safety Retrofit and Design of Structures



**Lead:** NIST/ASCEC

## **Partners:**

- ASCE Coalition (AISC, ACI, SFPE, NFPA, CASE, Council on Tall Buildings, ICC, SEAoNY, TMS, NCSEA)
- FEMA, USACE, NSF, NIST, NRC Canada, industry, universities

## **Need:**

- Current design practice does not consider fire as a design condition.
- No accepted science-base or tools to evaluate structural fire endurance.

## **What:**

- Standards and technology for fire safety retrofit and design of steel and concrete structures.
- Verified predictive tools and performance criteria to evaluate structural fire performance in real fires.

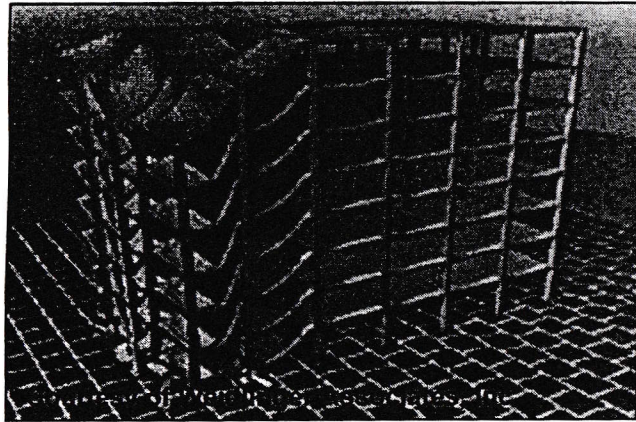
## **When:**

- Best practices guidance/tools (1-year)
- Interim standards/technology/tools (3-years)

**Cost:** \$12 M (Plus \$10 M test facility)



# Mitigation of Progressive Structural Collapse



Simulation of structure resistant to progressive collapse

## **Progressive collapse:**

- Spread of failure – by a chain reaction – that is disproportionate to localized triggering failure

## **Mitigation strategies:**

- System design concept
- Retard collapse after triggering event
- Built-in redundancy via alternate load paths
- Retrofit and design to “harden” structure

## **Need:**

- No accepted science-base or design practice to maintain overall structural integrity under multi-hazards (blast, explosion, fire, wind, earthquake)

## **What:**

- Standards and technology for retrofit and design of structures to mitigate progressive collapse.
- Verified predictive tools and performance criteria for evaluating vulnerability of structural systems to progressive collapse.

## **When:**

- Best practices guidance/tools (1-year)
- Interim standards/technology/tools (3-years)

## **Partners:**

- ASCE Coalition (AISC, ACI, SFPE, NFPA, CASE, Council on Tall Buildings, ICC, SEAoNY, TMS, NCSEA)
- FEMA, DTRA, NRC, NSF, USACE, NIST

**Lead:** NIST/ASCEC

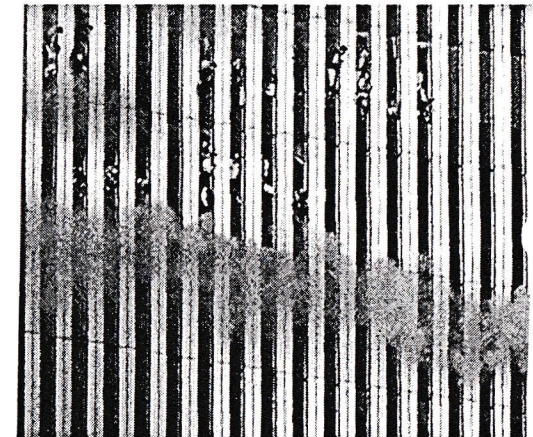
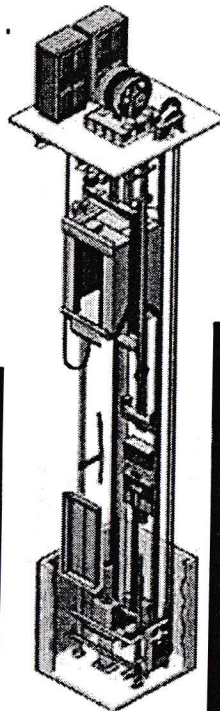
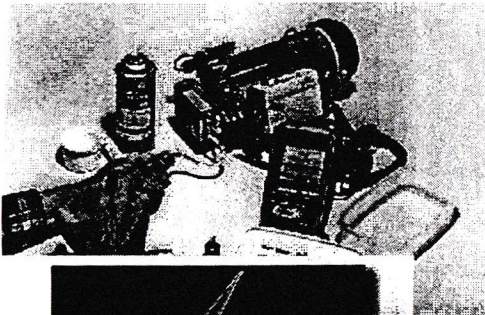
**Cost:** \$9 M



# III. Human Behavior, Emergency Response & Mobility \$6.5 M

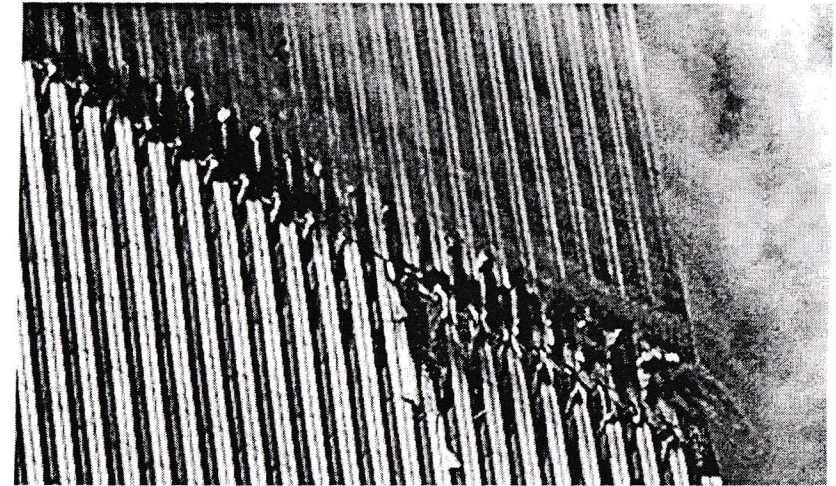
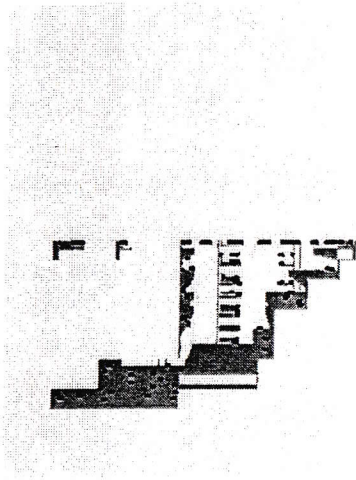
- Fire simulation re-creation tool
- Occupant behavior & response
- Tech. for emergency mobility
- Guidelines, equipment standards for fire & emergency responders

**Partners:** NFPA, FDNY, NYPD, WTC Occupants, FBI, FEMA, USFA, ATF, NRCC, universities, NSF, SFPE, IAFC,.

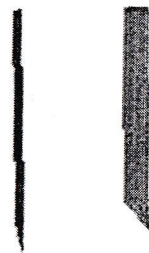




# Simulation Tool for Recreation of Fire and Smoke Movement Inside/Outside the WTC



NIST Smokeview 2.0Beta1\_0831 - DO NOT CITE

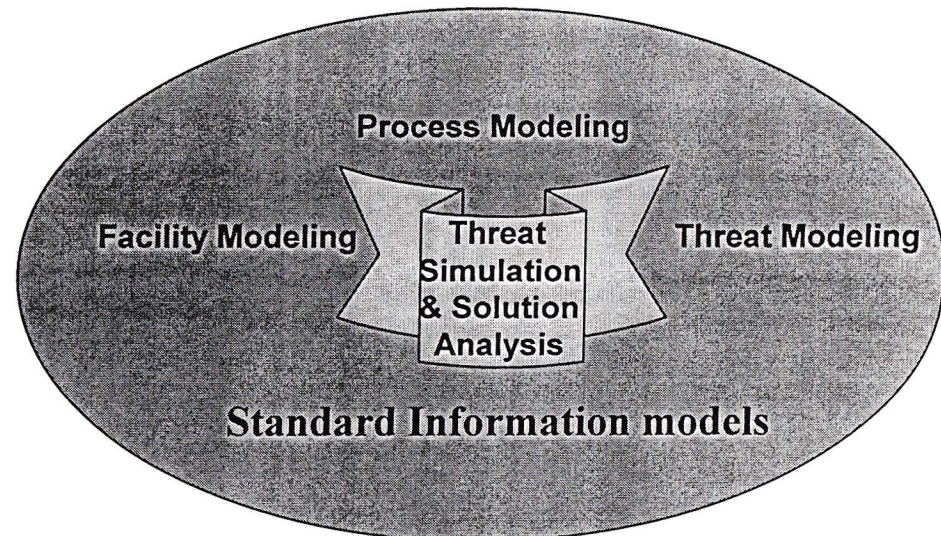
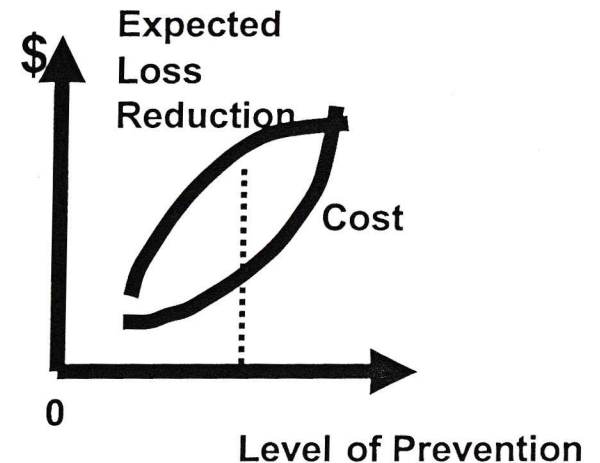




## IV. Building Vulnerability Reduction \$7.6 M

- Standard information models
- Guidelines, advanced technology for Chem. Bio. Rad. attacks
- Cost-effective risk management tools

**Partners:** IAI, FIATECH, ASHRAE, GSA, DOD, State Department, GSA, Wharton, NSF, CII, NCSBCS,...







# V. National Construction and Infrastructure Roadmap and Support \$6.0 M

## Concept:

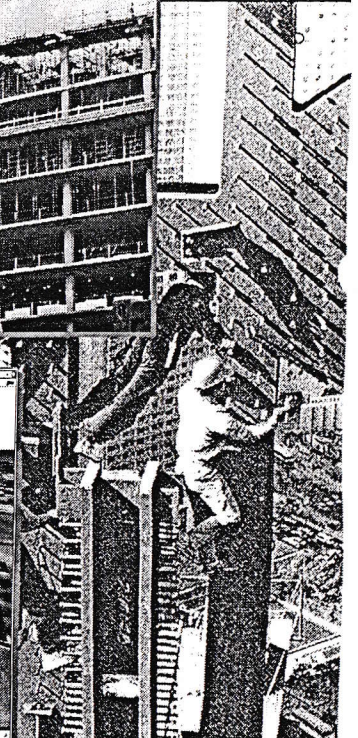
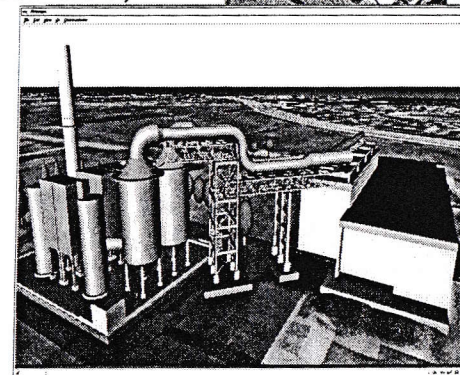
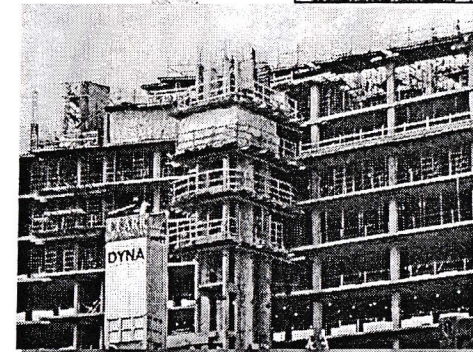
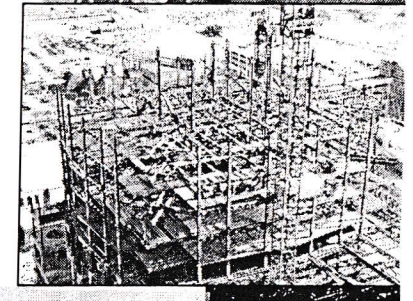
- Principal national forum through which facility owners and contractors deliver and disseminate results of research into ongoing construction projects and practice.
- Draw on top management, chief scientists/technology officers to direct and motivate needed change.
- Complement and support parallel efforts of engineering societies to improve technology, codes, and standards.

## Functions:

- Provide advice on best practices, guidance on vulnerability assessment, guidance on standards and codes needs.
- Conduct safety related R&D.
- Disseminate and implement R&D outputs.
- Act as clearinghouse (Q&As, industry inputs, needs/priorities, etc,...)
- Benchmark results

## Partners:

- Construction Industry Institute (CII)
- Civil Engineering Research Foundation (CERF)
- National Institute of Building Sciences (NIBS)





# Roles and Participation



Investigation

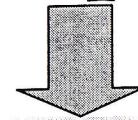
n

Research, testing/verification,  
demonstrations:

- **Structural Fire Protection**
- **Human Behavior, Emergency response & Mobility**
- **Building Vulnerability Reduction**

Improved tools, guidance for Industry  
Revisions to standards & codes

Construction Industry Roadmap  
Industry-Led dissemination  
& assistance programs



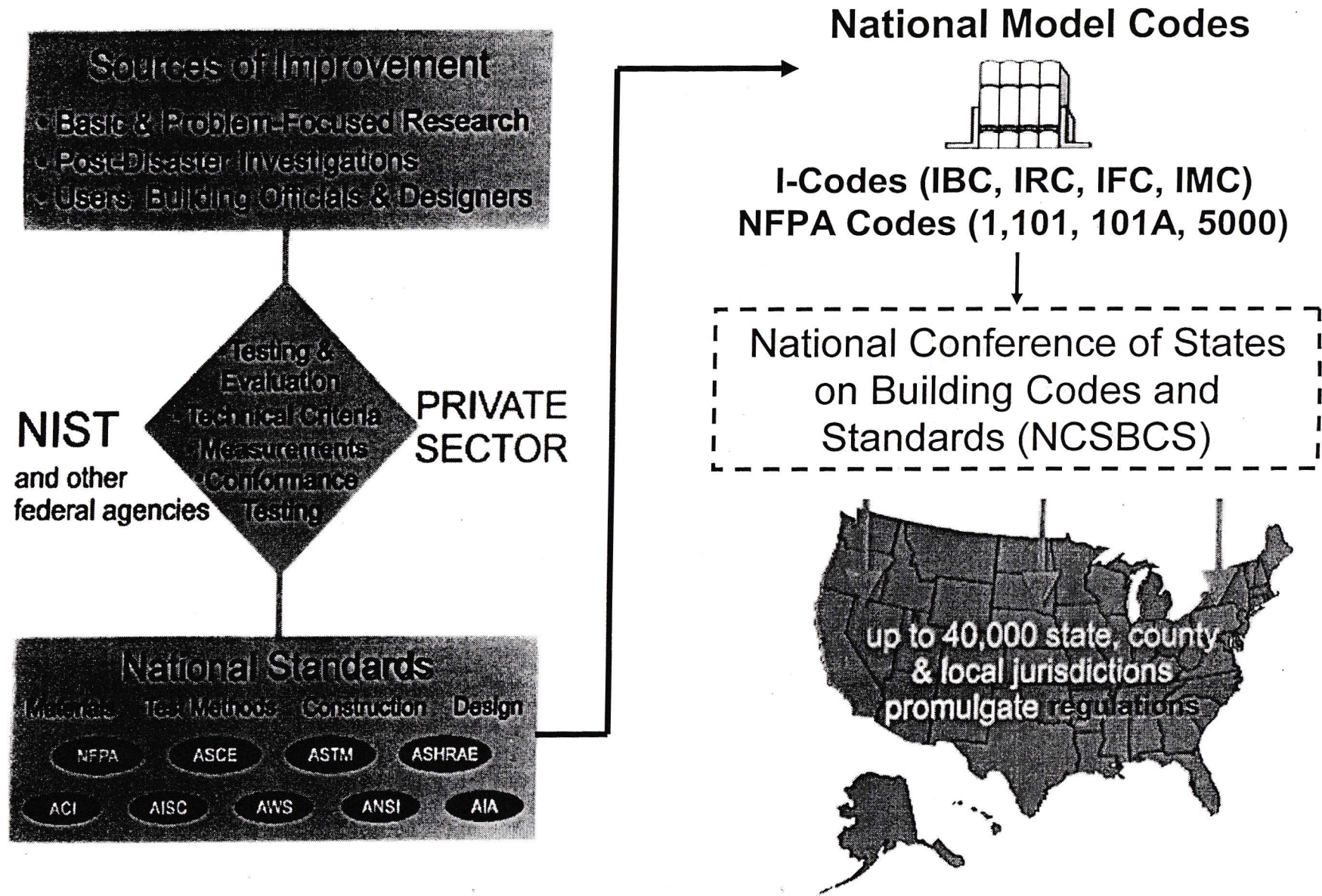
NIST staff, & external experts from  
Industry, Academe, Labs

NIST staff, & external experts from  
Industry, Academe, Labs;  
Industry/Owner-led demonstrations;  
Workshops, Symposia, Media, Web  
exposure for results, benefits.  
Standards and Codes participation.

Augment ongoing industry-led road map  
process;(FIATECH, CII, CERF,...)  
Complement public and private sector  
dissemination,technical assistance, &  
training programs. (e.g. CII, CERF, NIBS,  
NCSBCS,...)

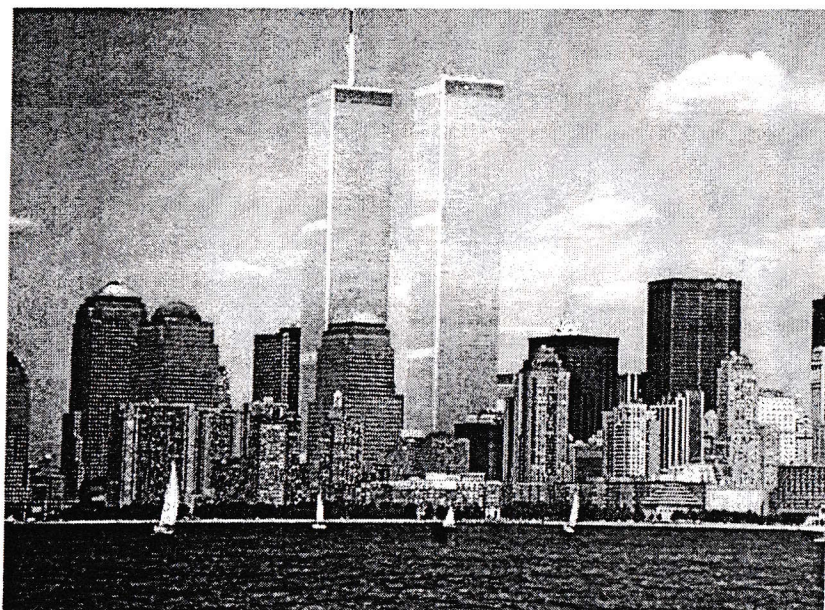


# BUILDING CODES AND STANDARDS





# **Public-Private Response Plan to September 11, 2001**



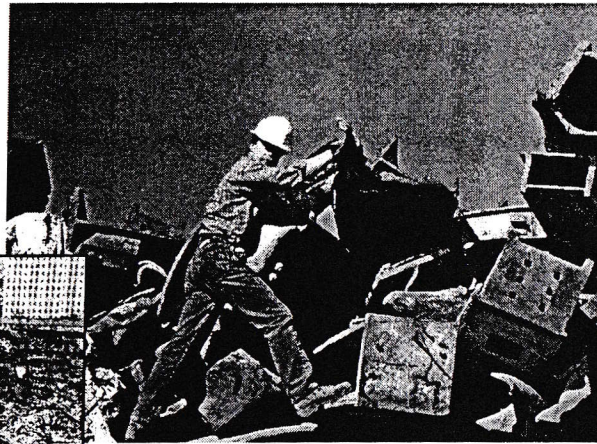
**S. Shyam Sunder**

Building and Fire Research Laboratory, NIST  
301-975-6713; [sunder@nist.gov](mailto:sunder@nist.gov)

**April 9, 2002**



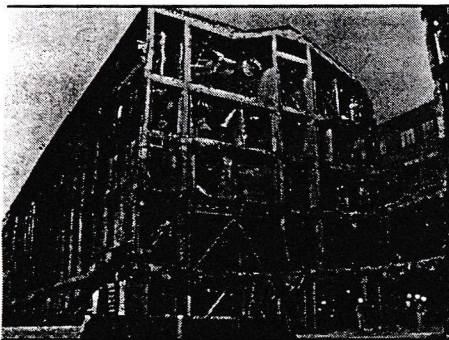
**John Gross** examines  
steel connection failures  
from WTC



WTC Field Observations  
Ground Zero looking east

# INITIAL NIST RESPONSE

- Code comparison study for FEMA
- 30-day Pentagon repair and rebuilding study

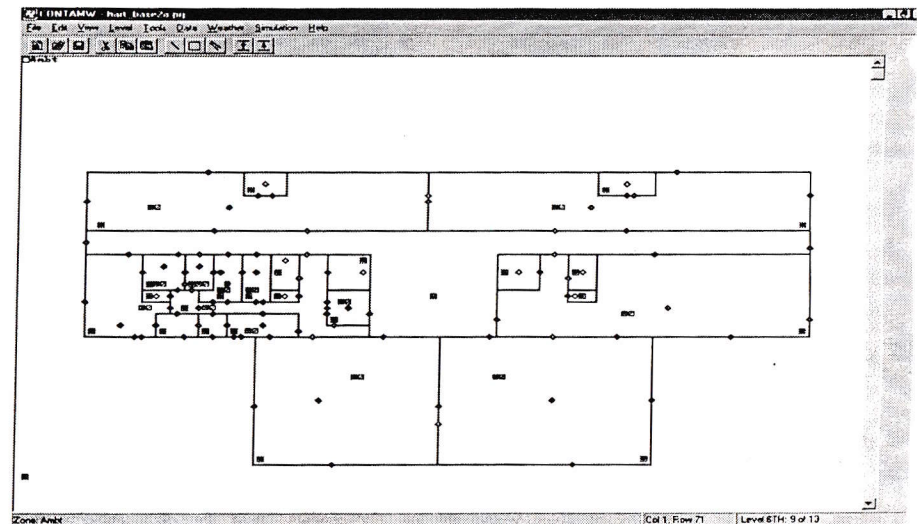


ASCE Team investigates  
damage to Pentagon



**Long Phan**, on  
ASCE Coalition  
Team

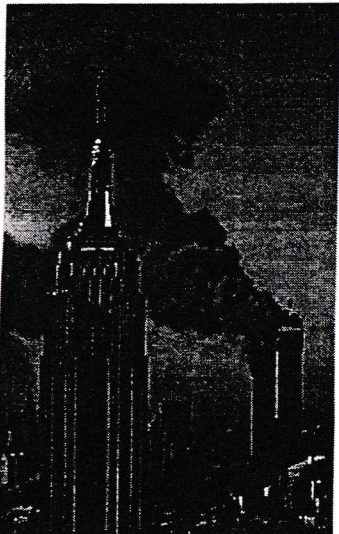
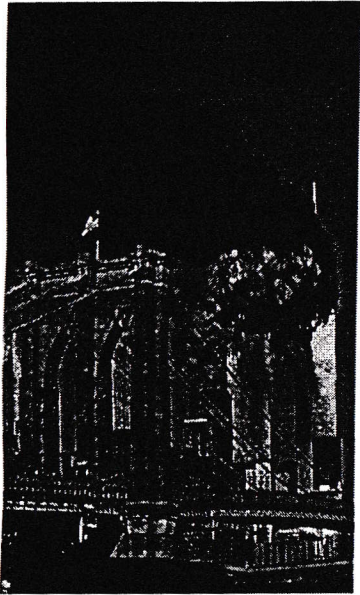
**Andy Persily** simulates contaminant  
dispersion in Hart Senate Building.





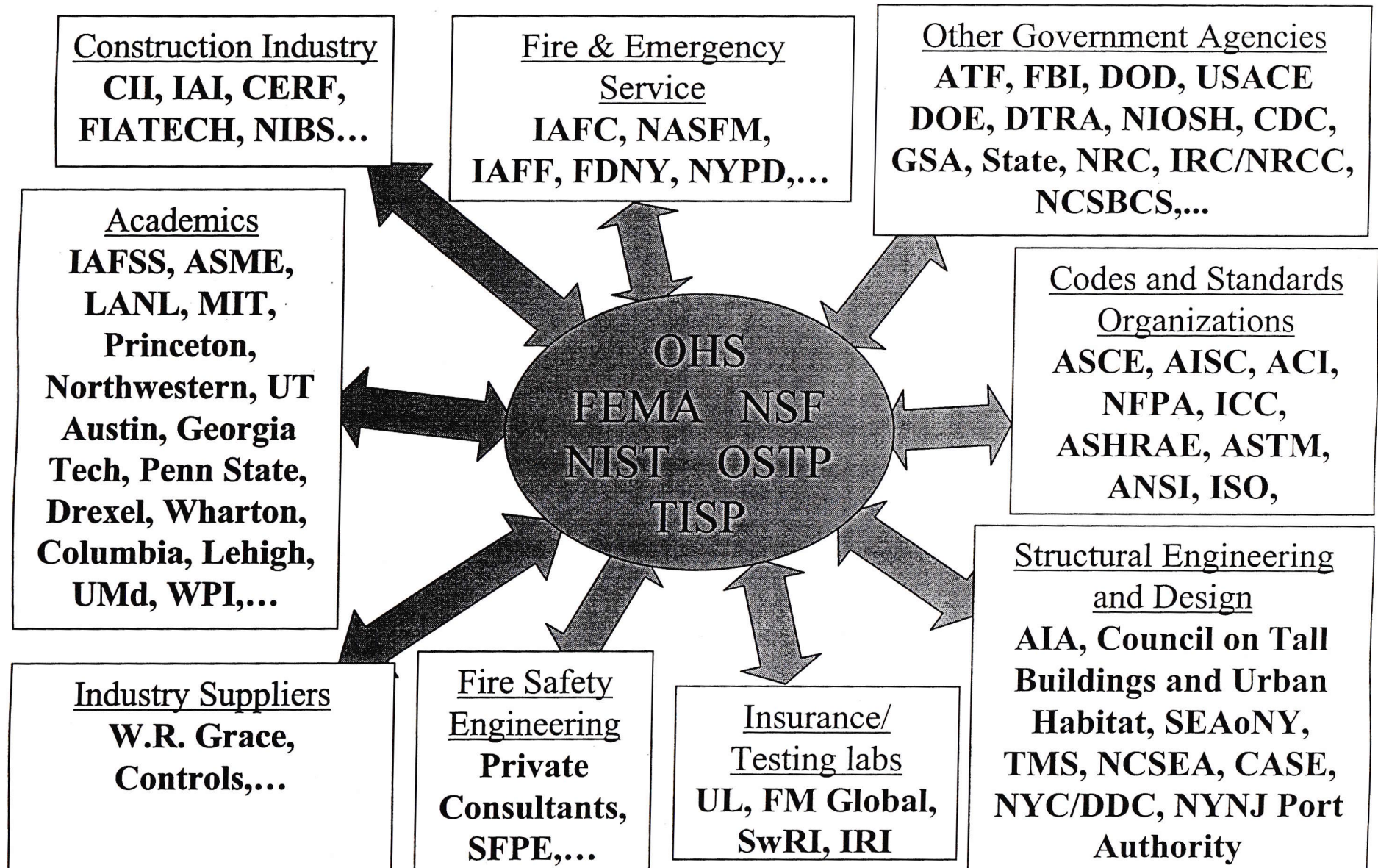
# National Need

- Worst-ever building disasters in human history.
- Unprecedented death and destruction in any single U.S. event.
- Never before have over 300 emergency responders lost their lives in a single incident.
- Unprepared for dramatic collapse of buildings occupied and in everyday use.
- Critical and urgent national need to:
  - Establish the **probable technical causes** of collapses and derive lessons to be learned
  - Disseminate immediate **guidance and tools** to assess and reduce future vulnerabilities
  - Produce the technical basis for **cost-effective changes** to national practices and standards
- Need integrated effort drawing on capabilities and expertise of a broad coalition of private and public sector organizations.



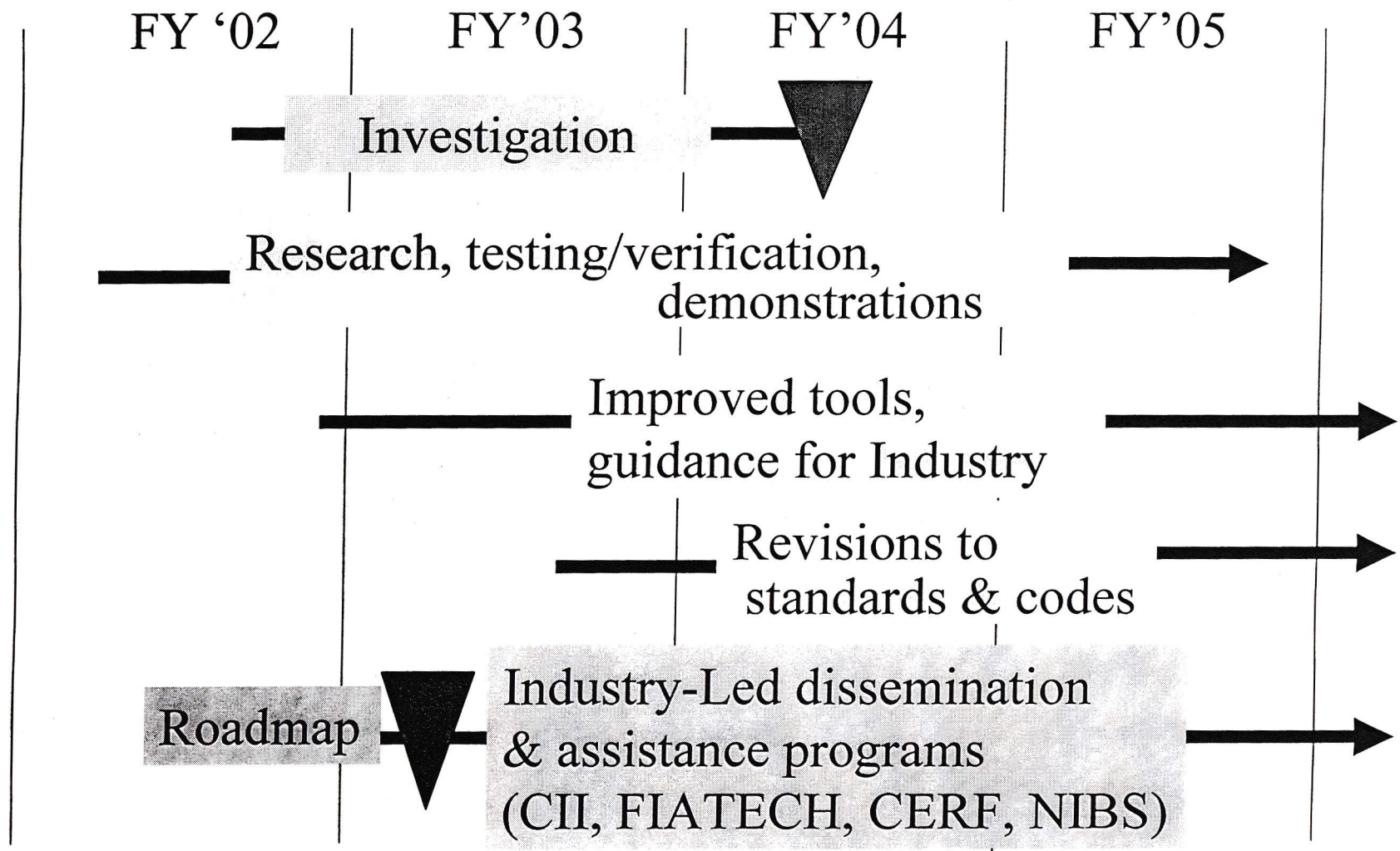


# Evolving Participation





# Overall Strategy and Plan





# **Response Plan - Overview**

**I. National Building and Fire Safety Investigation of the World Trade Center Disaster**

**II. Structural Fire Protection**

**III. Human Behavior, Emergency response & Mobility**

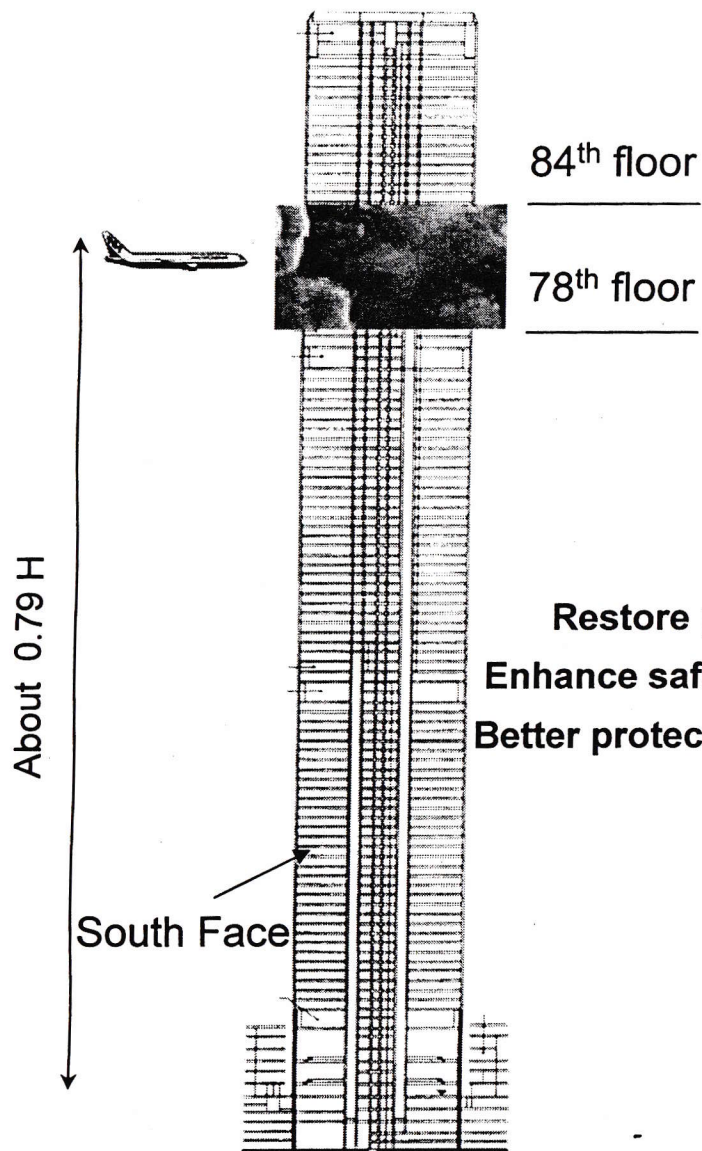
**IV. Building Vulnerability Reduction**

**V. National Construction and Infrastructure Roadmap and Support**

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**National Construction Safety Board**

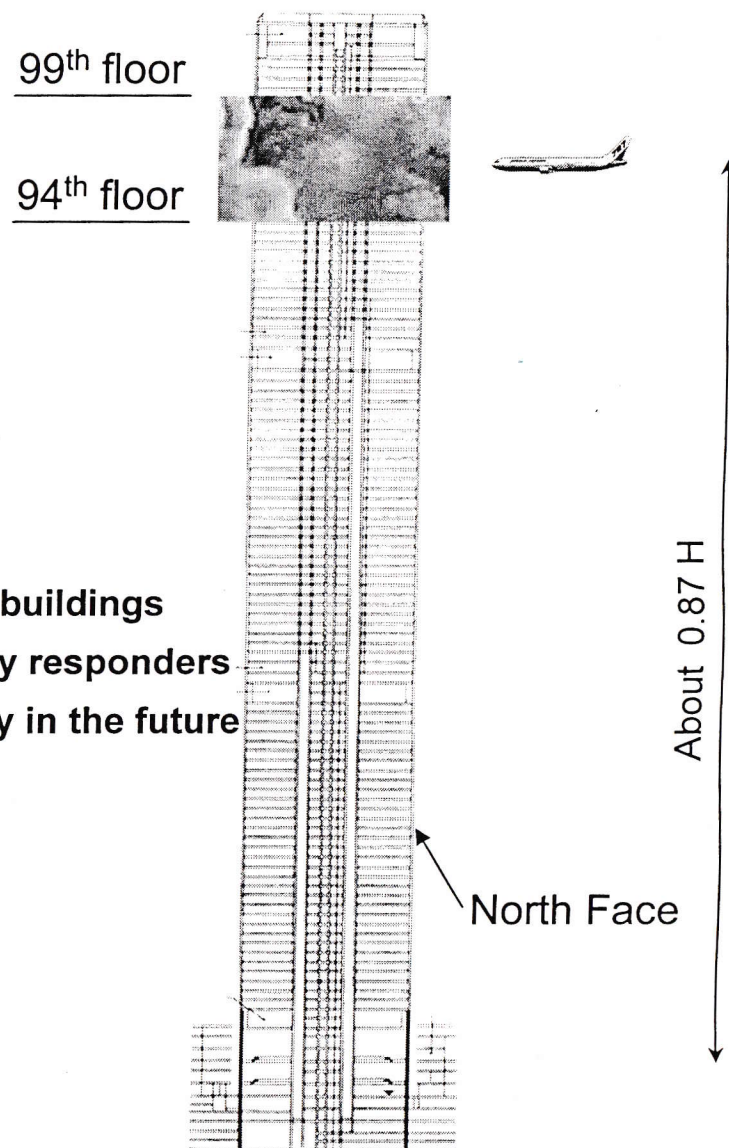




South tower: Hit at 9:03 AM  
Collapsed after 56 minutes

**Desired Outcome:**

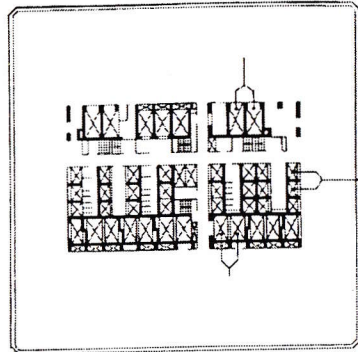
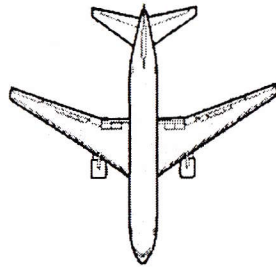
- Restore public confidence in tall buildings
- Enhance safety of fire and emergency responders
- Better protect occupants and property in the future



North tower: Hit at 8:45 AM  
Collapsed after 1 hour, 43 minutes

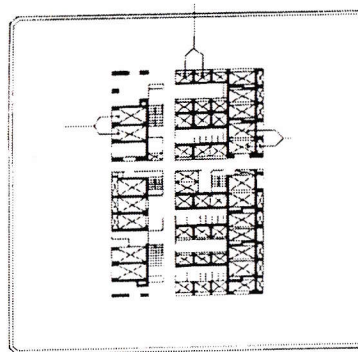


Point of impact:  
close to the  
center and  
nearly normal to  
the building

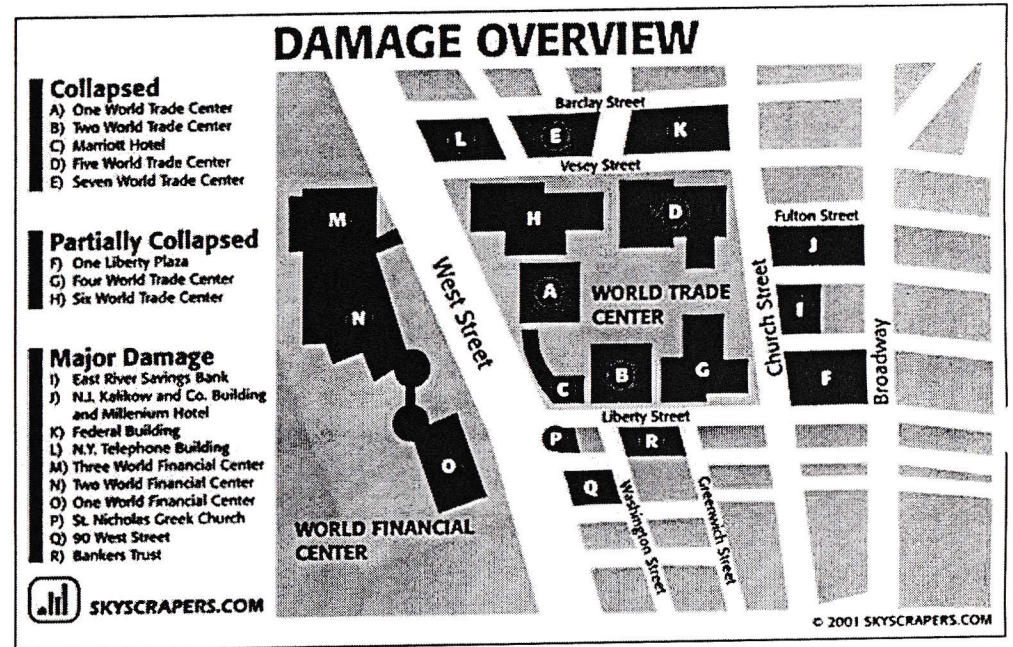
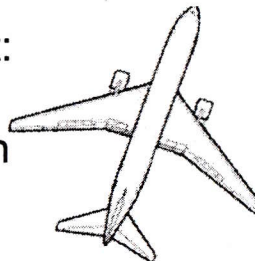


North tower

South tower



Point of impact:  
close to the  
corner and with  
an angle



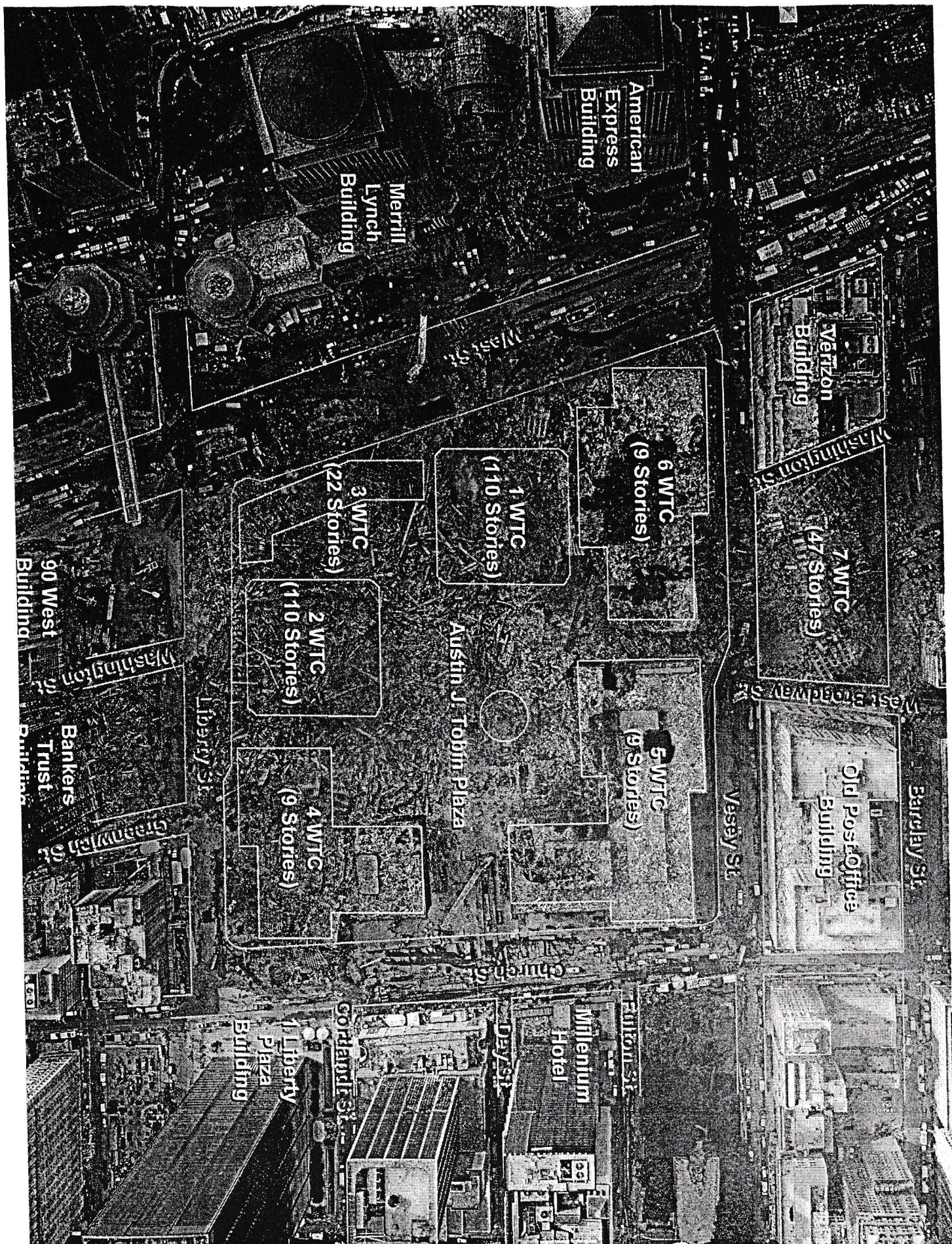
### Anecdotal Observations:

15 million sq. ft. lost on 9/11

Increasing numbers of tenants  
leaving Empire State Building

Building vacancy rates doubled  
in Manhattan







# I. National Building and Fire Safety Investigation of the World Trade Center Disaster (\$16.0 M)

## Goal:

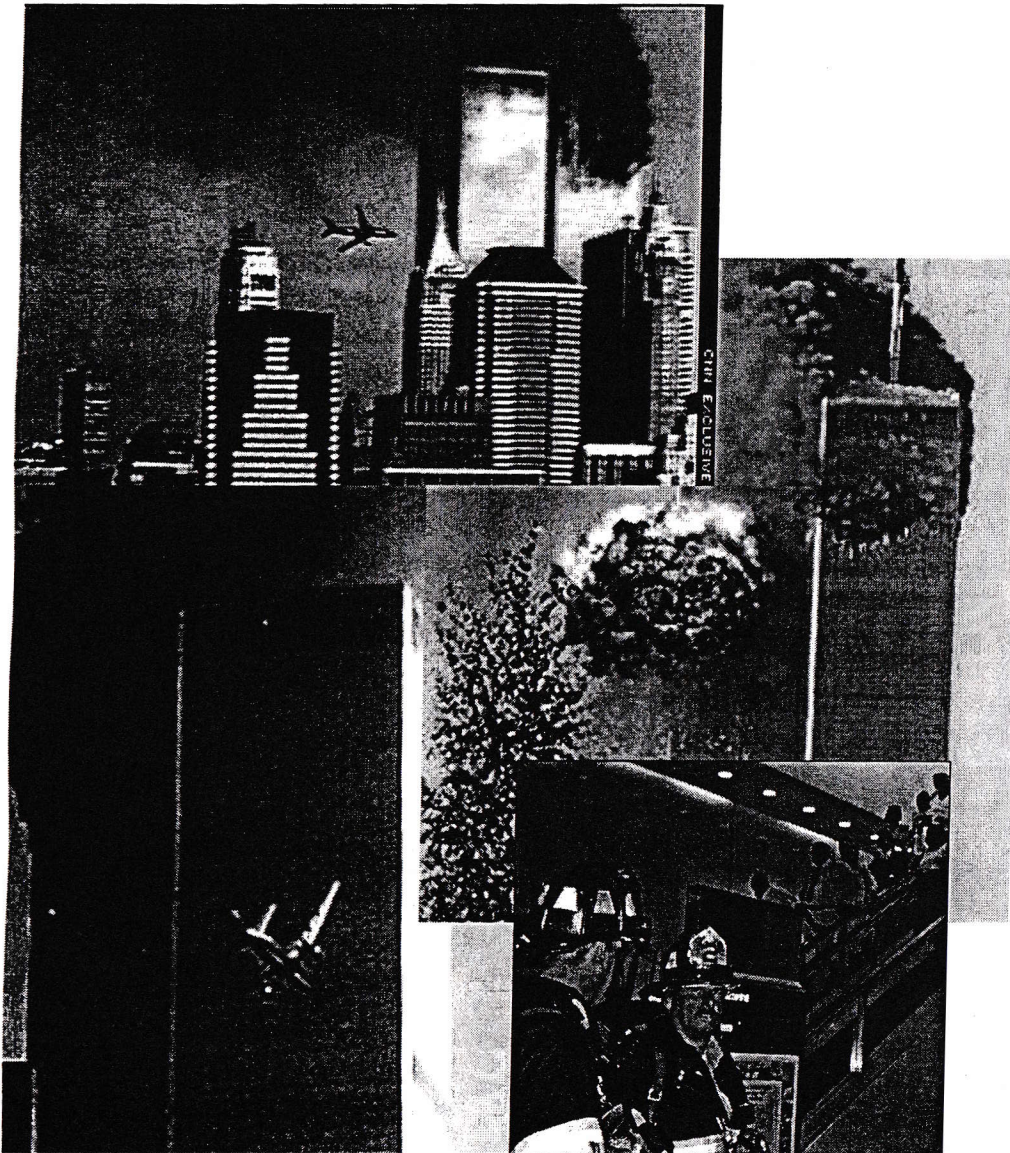
- To investigate the building construction, the integrity of the materials used, and all the technical conditions that combined to cause the disaster.

## Objectives:

- Determine technically, why/how the buildings, WTC 1 and 2, and possibly WTC 7, collapsed following the plane impacts.
- Determine why the injuries and fatalities were so low/high, including all technical aspects of fire protection, response, evacuation, and occupant behavior and emergency response.
- Determine whether state-of-the-art procedures and practices were used in the design, construction, operation, and maintenance of the WTC buildings as these factors related to the collapse of the buildings and associated injuries and fatalities.
- Determine whether there are new technologies/procedures emerging that could/should be employed in the future to reduce the potential risks of such collapse and loss of life and property.
- Identify building and fire codes, standards, and practices that warrant revision.

## What/When:

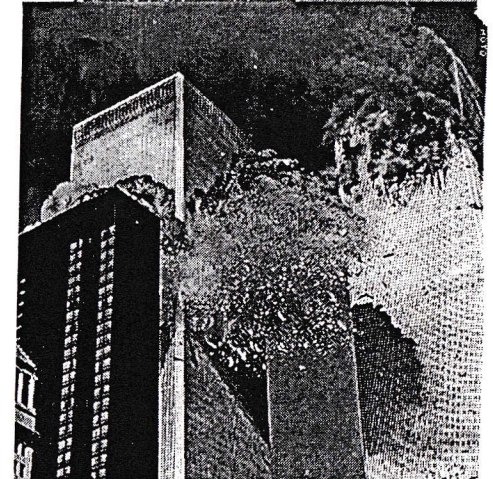
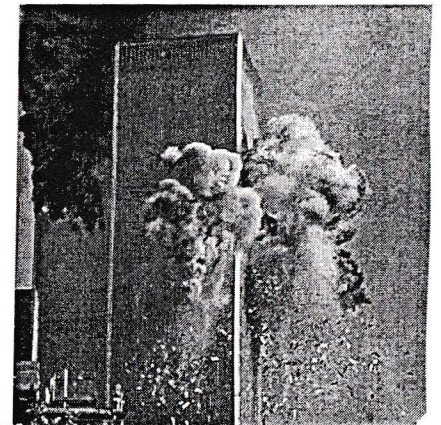
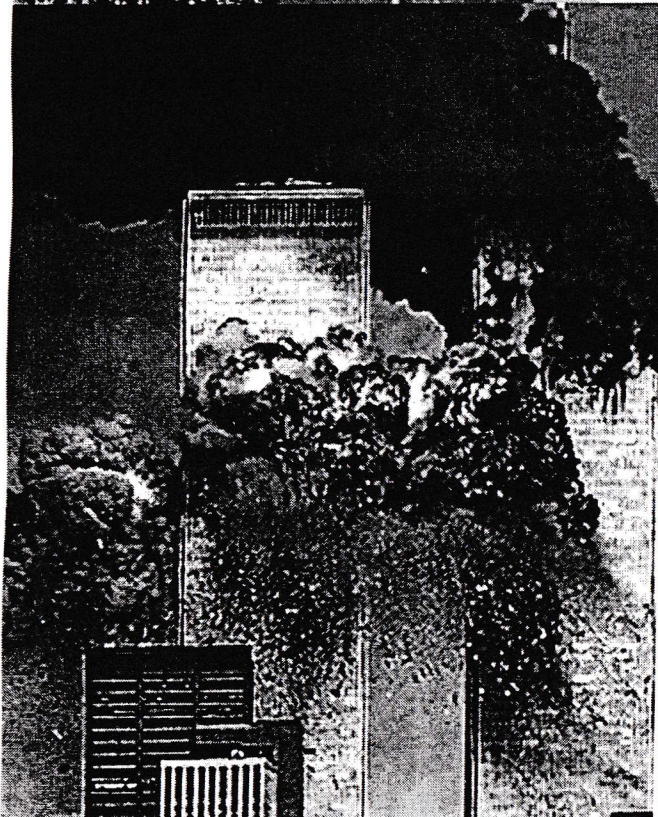
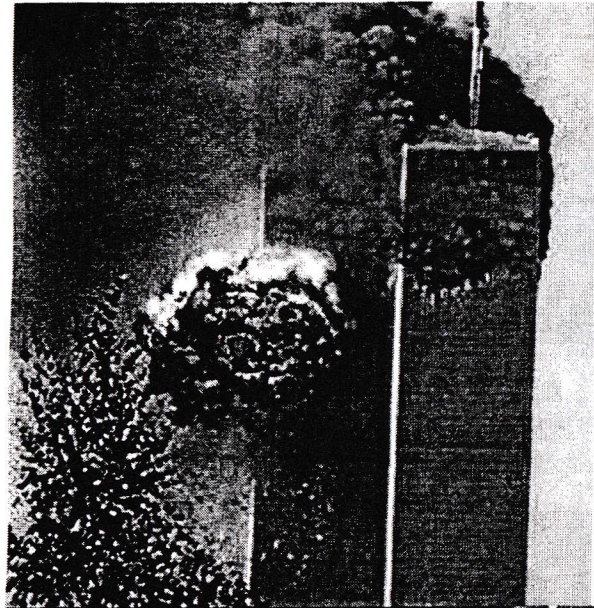
- Final Technical Report. Estimated 24 months.





# Guiding Principles

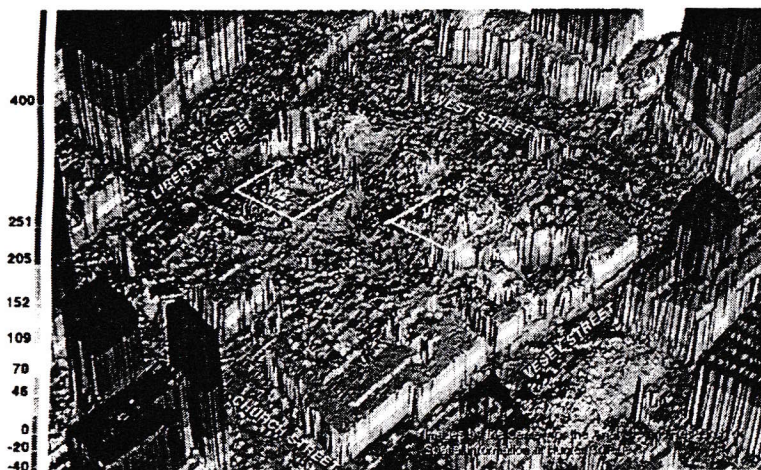
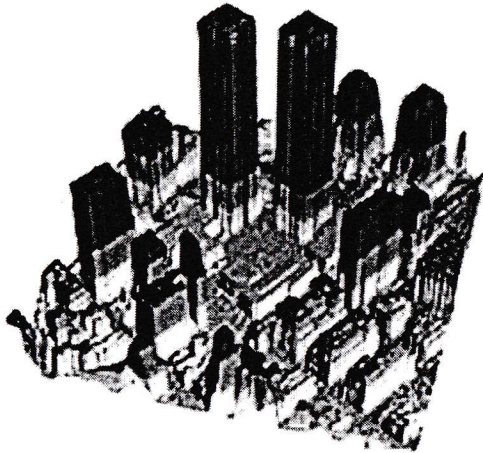
- NIST will ensure a totally independent technical investigation:
  - Planning and conduct of investigation;
  - Publishing findings and recommendations.
- Focus on creating new technical and/or scientific knowledge.
- Thorough, deliberate, and rigorous technical work.
- Objective and unbiased results.
- Timely and open public disclosure within legal bounds.
- Non-technical issues outside scope of NIST investigation:
  - No findings of responsibility or fault;
  - No determination as to behavior or negligence of any individual or organization.





# Technical Approach of Investigation

Before  
Image taken  
last year.



- **Data Collection:** inputs from PANYNJ and local authorities; building and fire protection design, plans, and specifications; construction, maintenance, operation records; building renovations and upgrades; video and photographic data; field data; interviews; emergency response records; and other records.
- **Building and Fire Codes and Practices:** analysis and comparisons of codes and standards then and now, and specifications actually used for WTC buildings; review and analysis of practices used in design, construction, operation, maintenance, repair, renovations, and upgrades.
- **Identification of Technical Issues and Major Hypotheses Requiring Investigation:** public input (open forum; website; federal register notice); convene expert panels to solicit input (experts in structural and fire protection engineering; experts in construction, maintenance, operation and emergency response procedures of tall buildings); findings and recommendations of FEMA-funded study and technical issues identified by other experts; analyze inputs and establish priorities; review by WTC Study Advisory Committee.
- **Collection and Analysis of Forensic Evidence:** metallurgical and mechanical analysis of steel to evaluate quality and estimate maximum temperatures; analysis of fire and elevator control panels.
- **Modeling, Simulation, and Scenario Analysis:** aircraft impact on structures; role of jet fuel and building contents in resulting fires; fire dynamics and smoke movement; thermal effect on structures and effect of fireproofing; effect of fire, connections, floor trusses, and core and exterior columns on structural response and vulnerability; occupant behavior and response; emergency mobility and egress; fire protection system design and vulnerability; competing hypotheses for structural collapse; bounds for probable collapse mechanisms.
- **Testing to Re-create Scenarios and Failure Mechanisms:** small and some real-scale re-creation tests to provide additional data & verify simulation predictions, especially effect of fires (ratings, connections, assemblies).
- **Technical Findings and Recommendations:** preparation of interim and final reports; review by WTC Study Advisory Committee; dissemination via published reports, web, and media.
- **Dissemination and Deployment of Findings:** via changes to standards, codes, and practices and participation with industry in their adoption and acceptance.